Electron-impact broadening of the $3s - 3p$ lines in low-Z Li-like ions

Yu. V. Ralchenkocor [a], [cor]Corresponding author. Present address: Atomic Physics Division, National Institute of Standards and Technology, Gaithersburg, MD 20899-8422 yuri.ralchenko@nist.gov H. R. Griem [b], I. Bray [c]

[a] *Faculty of Physics, Weizmann Institute of Science, Rehovot 76100, Israel*

[b] *Institute for Research in Electronics and Applied Physics, University of Maryland, College Park MD 20742*

[c] *Centre for Atomic, Molecular and Surface Physics, School of Mathematical and Physical Sciences, Murdoch University, Perth 6150, Australia*

The collisional electron-impact line widths of the $3s - 3p$ transitions in Li-like ions from B III to Ne VIII are calculated with the convergent close-coupling (CCC) method from the atomic collision theory. The elastic and inelastic contributions to the line broadening and their Z-scaling are discussed in detail, and comparisons with recent experimental and theoretical results are also presented. It is found that similar to our previous study of line broadening in Be-like ions, the difference between experimental and CCC results monotonically increases with the spectroscopic charge of an ion.

1 Introduction

The broadening of spectral lines in dense plasmas primarily stems from a complex interaction of an emitting atom with the perturbing plasma constituents [1]. Accordingly, the line shapes and shifts reveal (generally non-trivial) dependence on major plasma characteristics such as particle density and temperature, and hence can serve as important diagnostic tools. The complexity of the interaction, however, often impedes a reliable understanding of the line broadening, both experimentally and theoretically.

Although the line widths in hydrogen and hydrogen-like ions can normally be explained to a high level of accuracy, the recent studies on collisional broadening of isolated lines of multiply-charged ions have unveiled worrying disagreement between the experimental data and various theoretical calculations, including the advanced quantum-mechanical ones . An example is provided by the resonance $2s-2p$ line in the B III ion for which the experimental width [2] was found to be about a factor of two larger than non-perturbative results of both quantal and semiclassical [3,4]. As for the $2s3s-2s3p$ singlet and triplet lines in Be-like ions from boron to neon, it was shown that although the quantal results agree well with experimental line widths for low-charge ions, the deviation between experiment and theory monotonically increases along the isoelectronic sequence [5,6], reaching a factor of two for Ne VII. Such disagreement is indeed disturbing since the collisional broadening of the isolated lines in multiply-charged ions is primarily determined by the inelastic binary collisions, which in turn can be either experimentally assessed (as was done for the B III $2s-2p$ excitation cross section [7]) or reliably cross-checked by comparing with other theoretical calculations.

A reliable measurement of rather narrow line widths in multiply-charged ions poses demanding requirements both on the generation of the plasma properties required and the methods for an *independent* determination of electron density N_e and temperature T_e. In such benchmark experiments the laboratory plasmas, or plasma volumes, that are used in line broadening measurements have to be as uniform and stationary as possible and, if at all possible, to be free of various instabilities and turbulences. Needless to say, these requirements are not easily met in laboratory plasmas and are difficult to verify in astrophysical plasmas. Moreover, an independent measurement of N_e and T_e requires the most accurate available techniques which may not be applicable in some plasma conditions. It is thus not surprising that systematic measurements of broadening of isolated lines in multiply-charged ions were primarily conducted by two groups, namely, at the Institute of Physics in Belgrade, Yugoslavia, and at the Ruhr Universität in Bochum, Germany. Both groups have recently reported measurements of the $3s-3p$ line widths in Li-like ions from boron to oxygen (using a linear arc [8]) and from carbon to neon (using a gas-puff Z-pinch [9–11]), respectively, and the major plasma characteristics were independently measured for each shot. Furthermore, several other experimental results as well as a number of theoretical calculations are available for these transitions. Thus, the existing data could when taken as a whole provide a diverse set of results for comparison of measurements and theory.

In continuation of the previous quantal calculations of line broadening in multiply-charged ions [3,5,6], we present here a quantum-mechanical calculation of the electron-impact line widths of the $3s-3p$ transitions in Li-like ions from B III to Ne VIII. The paper is organized as follows. Section II contains the basic discussion of the theoretical method used for the present calculation. The convergent close-coupling method is applied for determination of both inelastic and elastic contributions to the line widths. The results of calculations as well as the comparison with experimental data are presented in Sec. III. The following Section deals with the scaling properties of the line widths and finally the conclusions are drawn in the last Section.

2 Theory

The calculational method implemented in the present work has been described in detail previously (see, e.g., Ref. [6] and references therein), and hence only the principal steps in the line width calculation are outlined here. The electron-impact full width at half-maximum (FWHM) of an isolated spectral line is calculated here using the Baranger formula [12], which represents the line width as a product of the electron density N_e and the sum of the thermally-averaged (i) inelastic (excitation, deexcitation, ionization, etc.) cross sections for all possible collisional transitions from the upper and lower levels of the radiative transition in question, and (ii) the difference squared of the non-Coulomb elastic amplitudes f_u and f_l of scattering from the upper and lower levels. This representation allows one to efficiently apply the computational methods developed for a general atomic collision theory to calculations of the impact line widths.

In this work both inelastic cross sections and elastic amplitudes are calculated with the convergent close-coupling (CCC) method [13], which is presently considered to be one of the most accurate techniques for electron-ion scattering problems. A detailed description of the method as well as recent applications of the CCC technique can be found in the review of Bray et al [14] and references therein. We only mention here that the basic idea of this method is the discretization of the continuum along with the use of the square-integrable Laguerre basis, which significantly facilitates the computational efforts.

It is well known that in multiply-charged ions the major contribution to the line width originates from excitation and deexcitation, and therefore a reliable estimate of the cross section accuracy would be important for an assessment of the line width accuracy. Since the existing experimental techniques do not allow one to measure the cross sections for transitions between excited states due to their small lifetimes, a comparison of different *theoretical* results seems presently to be the only tool for the error estimates. Fortunately, the Li-like ions represent a simple quasi-one-electron atomic system with practically pure LS-coupling for the lowest excited states (including the $n = 3$ terms), so that one would expect the modern calculational techniques to produce fairly accurate results for the collisional cross sections and amplitudes. Indeed, it was confirmed in a number of publications that the CCC excitation cross sections agree well with both the experimental data and other theoretical non-perturbative results for the ground state excitations. Such comparisons were done, e.g., for the R-matrix with pseudostates and K-matrix method results [15–17]. For higher-Z ions ($Z \geq 4$), a detailed comparison of all excitation cross sections between the states with the principal quantum number $n \leq 4$ has shown that the CCC data practically coincide with the perturbative Coulomb-Born-exchange calculations [18]. Furthermore, a recent paper on electron-impact excitation in Be II and B III (also including the transitions between the excited states up to $n \leq 4$) again demonstrated a high level of agreement between the CCC and the K-matrix cross sections [17]. Thus, the available data comparisons indicate that the CCC method seems to provide high accuracy for the excitation cross sections of Li-like ions and, correspondingly, for the inelastic contributions to the collisional line broadening. Also, it has to be added that, as one would expect, for all ions considered here the major contribution to the inelastic part comes from the collisional dipole-allowed $3s \rightarrow 3p$, $3p \rightarrow 3s$ and $3p \rightarrow 3d$ channels that amount to about 90% of the inelastic line width. The contribution of ionization and recombination channels was found to be negligible compared to (de)excitation processes.

The accuracy of the theoretical elastic contribution to the line widths still remains largely unknown. The main reason is that the elastic non-Coulomb scattering amplitudes as well as the angular-integrated elastic difference term (EDT) $\sigma_{EDT}(E) \equiv \int |f_u(\theta) - f_l(\theta)|^2 d\Omega$ are practically unavailable in the literature. However, given the high accuracy of the CCC inelastic cross sections, one would expect about the same accuracy for the elastic part as well. The EDT's for all ions from B III to Ne VIII have been calculated in the present work (see the Z-scaled results in Sect. 4). It was found that while the elastic cross sections $\sigma_{s,p}(E) \equiv \int |f_{s,p}(\theta)|^2 d\Omega$ follow the $1/E$ law for practically all energies from 0.1 to 100 eV, the EDTs show a sharper fall $\sigma_{EDT}(E) \sim 1/E^{\alpha}$ with $\alpha = 1.35 \div 1.45$, thereby pointing out a strong cancellation in the difference of elastic amplitudes. This steeper dependence on electron energy had already been noticed in our previous studies on the B III $2s-2p$ line and Be-like $2s3s-2s3p$ transitions [3,6].

3 Results and comparisons

The calculated elastic, inelastic and total FWHMs (in units of Å) for the electron density of 10^{18} cm^{-3} vs. electron temperature T_e in the range of $T_e = 2-20$ eV are presented in Table I for the ions from B III to F VII and in the range of $T_e = 2-50$ eV for Ne VIII, where experimental data are available for higher T_e. The inelastic contribution is seen to dominate over the elastic part for all calculated temperatures, although for small $T_e = 2$ eV the relative contribution of the elastic line width reaches as much as 50% for N V and O VI.The T_e-scaling of the calculated line widths for $T_e = 2-20$ eV is approximately given as

$$\lambda \propto T_e^{-\alpha}, \tag{1}$$

where α takes values of 0.17 (B III), 0.29 (C IV), 0.28 (N V), 0.31 for O VI, 0.26 (F VII) and 0.23 (Ne VIII). These values show a weaker than the $1/T_e^{0.5}$ dependence which is often used in the literature.

Figures 1-6 present the calculated CCC line widths and the available experimental and theoretical data scaled to the electron density of $\mathrm{N}_e = 10^{18}$ cm^{-3}. Most of the other theoretical results are taken from Ref. [8]. Below we often make use of the following designations: DSB – semiclassical results by Dimitrijević and Sahal-Brechot as cited in Ref. [8], DK – calculations made within the modified semiempirical method by Dimitrijević and Konjević as cited in Ref. [8], HB – semiclassical results by Hey and Breger [19], MNPSC – modified non-perturbative semiclassical method by Alexiou [20].

Note also that the measurements by the Belgrade group were carried out for low densities $\mathrm{N}_e = (0.3 \div 1.4) \times 10^{17}$ cm^{-3}, while the Bochum group measurements were performed on a linear gas-puff Z-pinch at densities exceeding 10^{18} cm^{-3}. The experimental error bars shown on the plots do not include the uncertainty of electron density measurements which can be as high as 15%. We now discuss the calculations for individual ions in more detail.

3.1 B III (Fig. 1)

For this ion, the $3s - 3p$ line width was measured only by the Belgrade group [8]. The typical experimental electron densities and temperatures were about 10^{17} cm^{-3} and 5 eV, respectively. This is the only case where the present CCC results practically coincide with the experimental data. Similarly, for the Be-like ions [6] an agreement was found only for the lowest-charge ion of B II. The semiclassical results of Griem and DSB, as cited in Ref. [8], exceed the experimental data by about 70 and 40%, respectively, while the semiempirical data of DK are seen to be within the errors bars, exceeding the CCC line widths by 15-20% over the temperature interval $T_e = 2 - 20$ eV. The only other quantum-mechanical results, by Seaton [21], also confirm the experimental data near $T_e = 5.5 - 6$ eV and, moreover, agree with the present calculations to within 10% over a wider range of T_e. Yet such good agreement for low temperatures may not be a measure of good agreement of elastic parts since the present calculations show that even for T_e as low as 2 eV the elastic contribution is only about one-fifth of the total line width (see Table I).

3.2 C IV (Fig. 2)

The theoretical and experimental data for the C IV $3s-3p$ line width are quite extensive. The older measurements by Bogen [22] and by El-Farra and Hughes [23] are well confirmed by the recent results of the Belgrade group [8]. The gas-puff Z-pinch data from Ref. [9], although being somewhat higher than the extrapolated T_e-trend from other measurements, nevertheless overlap with the error bars from the Belgrade results. The recent measurements of Srecković et al. [24] on a linear low-pressure pulsed arc were performed for low temperatures $T_e \sim 2$ eV and showed a significant spread. As for the theoretical results, Seaton [21] carried out a quantum-mechanical R-matrix calculation within the framework of the Opacity Project for this line width taking into account the perturbing $n = 2$ and $n = 3$ states. Later Burke [25] improved Seaton's calculations using the same method but adding $n = 4$ states, which resulted in a moderate increase of less than 10% to the line widths. The present CCC results are seen to agree excellently with Burke's calculations, particularly for higher temperatures where the inelastic contribution dominates. Even for the lowest temperatures ($T_e \sim 4$ eV) the difference is well within 10%. However, as can be seen from Fig. 2, the recent experimental results [8,9] exceed the CCC line widths by up to 30%.

3.3 N V (Fig. 3)

Experimental line widths for N V are available from both Bochum and Belgrade experiments, the former having rather large error bars for the electron temperature. Of the available theoretical results, the semiclassical method of Griem [1] provides very good agreement with both sets of experimental data over the range of temperatures from 6 to 24 eV. It is noted that the T_e-dependence of line widths is very similar for the CCC, Griem and DK results, while the semiclassical DSB data seem to decay faster for higher T_e.

3.4 O VI (Fig. 4)

The available measurements for this ion were carried out over a rather large range of electron temperatures, $T_e = 5 - 18$ eV, although the error bars here are quite significant, and therefore it is difficult to reach conclusions regarding the temperature dependence of the data. Figure 4 shows that both sets of experimental data for O VI well agree with the semiclassical calculations of DSB. The only other quantum-mechanical data of Seaton for $T_e \approx 11$ eV practically coincide with the present calculations, and the DK results are again within 20% from the CCC data. The semiclassical results by Griem, Hey and

Breger, and Alexiou agree with each other and are at the lower edge of the experimental error bars.

3.5 F VII (Fig. 5)

The only available experimental data for this line for $T_e = 14 - 18$ eV and electron densities in the range $(1.5-3) \times 10^{18}$ cm^{-3} were reported in Ref. [10]. Again, similar to the O VI case, the agreement with the semiclassical results of DSB is very good, while all other theoretical results are much lower than the experiment.

3.6 Ne VIII (Fig. 6)

This is the case where the difference between the experiment and *all* existing theoretical results is the largest. The broadening of the Ne VIII $3s - 3p$ line at the highest electron temperatures of 30 and 42 eV was measured by the Bochum group a decade ago [9,10] and has recently been remeasured on the same experimental setup [11]. The latest data are seen to be closer to the theoretical values (Fig. 6), so that DSB and Griem's results are at the lower edge of the error bars. However, the other available theoretical data are much lower, and the disagreement with the experiment exceeds 50% for the MNPSC method, DK and HB results, while the CCC line widths are factor 2.3 smaller than the data from Ref. [11].

4 Discussion and Scaling Properties

As has already been mentioned in the Introduction, in the previous work on collisional broadening in Be-like ions [6] we found that the CCC results and experimental data systematically diverge along the isoelectronic sequence. A reader might have already noticed that this is also the case in the present comparison. Figure 7 shows the ratio of experimental to calculated CCC line widths for the $3s-3p$ transition as a function of atomic number for all Belgrade and Bochum data points presented in Figs. 1-6. (The two older data points for Ne VIII [9] are not included in this plot.) The ratios using the Belgrade experimental results are shown by the large shaded circles, while those using the Bochum data are shown by the large open circles. The dashed line is added to the plot in order to make the trend more visible. Further, we add the ratios for the $2s3s - 2s3p$ line widths in Be-like ions [6] (small shaded and open squares for the Bochum and Belgrade data, respectively) to emphasize that the ratios are indeed very close for both isoelectronic sequences.

The fact that a very similar behavior in terms of the ratio between the experimental and quantum-mechanical line widths is found for completely different experiments suggests a similar physical rather than instrumental or systematic experimental mechanism responsible for the deviation of experimental and theoretical widths. As has already been mentioned above, in most of the experiments an independent diagnostic is required for a reliable determination of the electron density (and temperature). In order to eliminate the broadening due to the opacity effects, the measurements were done using small amounts of test gas containing the impurity ions added to a major bulk gas. In both series of experiments, N_e was determined from the bulk plasma (hydrogen in Bochum experiments and helium in Belgrade measurements) using 90^o Thomson scattering of laser light, or a well-known dependence of the Paschen-α line of He II on N_e, respectively. The resolved impurity peak in the former measurements indicated that the impurity density was $\leq 1\%$ of N_e. Such measurements are obviously carried out macroscopically and thus are insensitive to the density fluctuations near the multi-charged impurity ions. The local increase of electron density near an impurity ion which has a higher Coulomb charge than the background ions is obvious already from the Debye-Hückel picture of a charge screening in plasmas. The recent detailed classical many-body and molecular-dynamics calculations [26] of non-linear behavior of electrons near a positive impurity ion for various plasma conditions (with a strong coupling constant $\Gamma = 0.03 - 0.5$ which is much larger than that in both Belgrade and Bochum experiments) indeed show an increase of electron density in the ion vicinity. However, preliminary estimates based on the Debye-Hückel picture do not seem to support the importance of this phenomenon for line broadening in the experiments discussed here. Needless to say, a detailed investigation of how the local density fluctuations near impurity ions could influence the spectral line broadening would obviously be very helpful.

It should also be mentioned that the extra contribution to the line widths from ion-impact broadening may be quite reliably estimated using the semiclassical calculations of Ref. [8]. For the ions from B III to O VI the ion width was found to not exceed 5% of the electron FWHM and thus it can be safely neglected here.

The scaling of the impact widths for isolated lines has long been a subject of detailed studies. The possibility of accurately predicting the unknown line widths from those already measured and/or calculated is always a strong impetus to attack this problem. The regularities of the Stark broadening along isoelectronic sequences have been discussed for some time in connection with the critical reviews of Stark broadening data (see, e.g., [27] and references therein). The scaling of the line widths with the ion spectroscopic charge can be easily derived from the Baranger formula. If one assumes that only one perturbing transition contributes to the line width, then the inelastic contribution is proportional to:

$$\Delta\lambda_{inel} \propto \lambda^2 \langle \sigma v \rangle . \tag{2}$$

For the $\Delta n = 0$ transition the wavelength scales as $\lambda \propto 1/Z$, the threshold cross section $\sigma \propto 1/Z^3$, so that for the line width one obtains $\Delta\lambda_{inel} \propto 1/Z^5$ for the same electron temperatures. Our previous study of excitation cross sections in Li-like ions with spectroscopic charge $Z \geq 4$ [18] showed that the scaling of the CCC cross sections slightly differs from the $1/Z^3$ dependence, and for the $3s - 3p$ and $3p - 3d$ transitions, which are dominant in the present case, the scaling is $1/\left(Z + 1.75\right)^{3.4}$ and $1/\left(Z + 0.44\right)^{3.5}$, respectively. This results in modified scaling properties for the CCC line widths which are found to be approximately

$$\Delta\lambda_{inel}^{CCC} \propto 1/Z^{17/4} \tag{3}$$

for the ions considered in this work. The scaled products $\Delta\lambda_{inel}^{CCC} \times Z^{17/4}$ for all ions from B III to Ne VIII are presented in Fig 8(a). One can see that the scaling is accurate to only 10% for all values of T_e and significantly improves with the increase of the spectroscopic charge.

The scaling of the elastic part of the line width, however, is not as obvious as that of the inelastic one. For the problem in question the elastic scattering is dominated by the polarization potential $\sim 1/r^4$ resulting from interactions between the $n = 3$ states. The solutions for the elastic cross sections in a central field of the modified Blumington polarization potential [28]

$$V\left(r\right) = -\frac{\alpha_D}{2\left(r^2 + d^2\right)^2}, \tag{4}$$

where α_D is the dipole polarizability and d is the characteristic length of the order of the atomic orbit, are well known for the Born and semiclassical approximations. Since for the $\Delta n = 0$ transitions $\alpha_D \sim 1/Z^3$ and assuming $d \sim 1/Z$, the Z-scaling in these cases is $\sigma \sim 1/Z^3$ and $\sigma \sim 1/Z^{7/3}$, respectively. However, we find that the elastic cross sections $3s - 3s$ and $3p - 3p$ as well as the elastic difference term exhibit a weaker scaling law, namely, $\sigma \sim 1/Z^{3/2}$. This difference may result from the fact that the theoretical Z-dependence of the Born and semiclassical cross sections is ususally derived assuming that the major contribution comes from the high partial waves $L \gg 1$. On the contrary, the present CCC calculations show that most of the elastic cross sections is provided by the low partial waves with $L \lesssim 3 - 4$ only. Returning to the Z-scaling of the elastic line widths, one immediately obtains that for the same electron temperatures and $\sigma_{EDT} \sim 1/Z^{3/2}$ the elastic contribution to the line width scales as

$$\Delta\lambda_{el}^{CCC} \propto 1/Z^{7/2}. \tag{5}$$

Somewhat better accuracy is actually achieved with a $1/Z^{15/4}$ scaling which is presented in Fig. 8(b), where the scaled line widths $\Delta\lambda_{el}^{CCC} \times Z^{15/4}$ are plotted vs. electron temperature.

5 Conclusions

One of the most powerful techniques in the atomic collision theory–the convergent close-coupling method–is applied here to the electron-impact broadening of the isolated $3s - 3p$ lines in Li-like ions from B III to Ne VIII. The elastic and inelastic contributions to the line width are explicitly calculated and tabulated for electron temperatures from 2 to 20 eV. A comparison with available experimental data (mostly from the Belgrade and Bochum groups) shows that although the quantum-mechanical data presented here agree well with the measurements for lowest-charge ions, the disagreement progressively increases with an increase of the ion charge. In no case is the experimental line width *smaller* than the quantum-mechanical one, suggesting some additional line broadening process in the higher-Z experiments.

6 Acknowledgments

We are grateful to H.-J. Kunze and Y. Maron for valuable discussions and comments and to S. Alexiou for providing the MNPSC data prior to publication. This work was supported in part by the Israeli Ministry of Absorption and Israeli Academy of Sciences (Yu. V. R.) and by the US National Science Foundation (H.R.G.). I.B. acknowledges the support of the Australian Research Council.

References

[1] Griem HR. Spectral Line Broadening by Plasmas. New York: Academic, 1974; Principles of Plasma Spectroscopy. Cambridge: Cambridge University Press, 1997.

[2] Glenzer S, Kunze HJ. Stark broadening of resonance transitions in B III. Phys Rev A 1996 53:2225-9.

[3] Griem HR, Ralchenko YuV, Bray I. Stark broadening of the B III 2s-2p lines. Phys Rev E 1997;56:7186-92.

[4] Alexiou S, Lee RW. Electron line broadening in plasmas: resolution of the quantum vs. semiclassical calculations puzzle. Proceedings of the 15th International Conference on Spectral Line Shapes. New York: AIP Press, 2001.

[5] Ralchenko YuV, Griem HR, Bray I, Fursa DV. Quantum-mechanical calculation of Stark widths of Ne VII n = 3, Δn = 0 transitions. Phys Rev A 1999;59:1890-5.

[6] Ralchenko YuV, Griem HR, Bray I, Fursa DV. Electron collisional broadening of 2s3s-2s3p lines in Be-like ions. J Quant Spectrosc Radiat Transfer 2001; 71:595-607.

[7] Woitke O, Djurić N, Dunn GH, Bannister ME, Smith ACH, Wallbank B, Badnell NR, Pindzola MS. Absolute cross sections for excitation of the 2s ^{2}S $\rightarrow$ 2p ^{2}P transition in B^{2+} and for electron-impact single ionization of B^{2+}. Phys Rev A 1998;58:4512-7.

[8] Blagojević B, Popović MV, Konjević N, Dimitrijević MS. Stark broadening parameters of analogous spectral lines along the lithium and beryllium isoelectronic sequences. J Quant Spectrosc Radiat Transfer 1999;61:361-75.

[9] Glenzer S, Uzelac NI, Kunze HJ. Stark broadening of spectral lines along the isoelectronic sequence of Li. Phys Rev A 1992; 45:8795-802.

[10] Glenzer S, Uzelac NI, Kunze HJ. Stark broadening of 3s-3p transitions in F VII. Proceeding of the 7th International Conference on Spectral Line Shapes. New York: Nova Science Publishers Inc., 1993.

[11] Hegazy H, Seidel S, Wrubel Th, Kunze HJ. J Quant Spectrosc Radiat Transfer 2003;this volume.

[12] Baranger M. General Impact Theory of Pressure Broadening. Phys Rev 1958;112:855-65.

[13] Bray I, Stelbovics A. Calculation of Electron Scattering on Hydrogenic Targets. Adv At Mol Opt Phys 1995;35:209-54.

[14] Bray I, Fursa DV, Kheifets A, Stelbovics A. Electrons and photons colliding with atoms: development and application of the convergent close-coupling method. J Phys B 2002;35:R117-46.

[15] Bartschat K, Bray I. Calculation of electron impact excitation and ionization of Be^+. J Phys B 1997;30:L109-14.

[16] Marchalant PJ, Bartschat K, Bray I. Electron-impact excitation and ionization of B^{2+}. J Phys B 1997;30:L435-40.

[17] Starobinets A, Bray I, Vainshtein LA, Ralchenko YuV, Maron Y. Excitation Cross Sections for Li-like Ions of Beryllium and Boron. Phys Scr 2003;to be published.

[18] Fisher VI, Ralchenko YuV, Bernshtam VA, Goldgirsh A, Maron Y, Vainshtein LA, Bray I. Electron-impact-excitation cross sections of lithiumlike ions. Phys Rev A 1997, 56:3726-33.

[19] Hey JD, Breger P. S Afr J Phys 1982, 5:111; Calculated stark widths of oxygen ion lines. J Quant Spectrosc Radiat Transfer 1980;24:349-64.

[20] Alexiou S. Private communication, 2002.

[21] Seaton MJ. Atomic data for opacity calculations. VIII. Line-profile parameters for 42 transitions in Li-like and Be-like ions. J Phys B 1988;21:3033-54.

[22] Bogen P. Pressure broadening of multiply ionized carbon lines. Z Natur A 1972;27:210-14.

[23] El-Farra MA, Hughes TP. Stark broadening of lines from multiply-charged carbon ions in a high-density arc plasma. J Quant Spectrosc Radiat Transfer 1983;30:335-43.

[24] Srećković A, Drinčić V, Bukvić S, Djeniže S. Stark broadening parameters in C II, C III and C IV spectra. J Phys B 2000;33:4873-90.

[25] Burke VM. Atomic data for opacity calculations. XVII. Calculation of line broadening parameters and collision strengths between n=2,3 and 4 states in C IV. J Phys B 1992;25:4917-28.

[26] Talin B, Calisti A, Dufour E, Dufty J. Classical dynamics of electrons surrounding ions in hot and dense plasmas – related topics. J Quant Spectrosc Radiat Transfer 2001;71:729-37.

[27] Konjević N, Lesage A, Fuhr JR, Wiese WL. Experimental Stark widths and shifts for spectral lines of neutral and ionized atoms. J Phys Chem Ref Data 2002;1:819-927.

[28] McDaniel EW. Atomic collisions: electron and photon projectiles. New York: Wiley-Interscience, 1989.

Figure captions.

Figure 1. Collisional line widths for the 3s-3p transition in B III. Experiment: Ref. [8] –. Theory: present work – solid line with solid circles, Griem (as cited in Ref. [8]) – dot line, DSB [8] – short-dash line, Seaton [21] – dot-dash line, DK (as cited in Ref. [8]) – long-dash line.

Figure 2. Collisional line widths for the 3s-3p transition in C IV. Most of notations are the same as in Fig. 1. Experiment: Ref. [9] – $\bigcirc$, Ref. [22] – , Ref. [23] – $\triangle$, Ref. [24] – $\bigtriangledown$. Theory: Alexiou [20] – $\times$, Burke [25] – dot-double-dash line.

Figure 3. Collisional line widths for the 3s-3p transition in N V. Most of notations are the same as in Fig. 1 and 2.

Figure 4. Collisional line widths for the 3s-3p transition in O VI. Most of notations are the same as in Fig. 1 and 2. Theory: Seaton [21] – $*$, Hey and Breger [19] – dash-double-dot line.

Figure 5. Collisional line widths for the 3s-3p transition in F VII. Most of notations are the same as in Fig. 4. Experiment: Ref. [10] – $\bigcirc$.

Figure 6. Collisional line widths for the 3s-3p transition in Ne VIII. Most of notations are the same as in Fig. 4. Experiment: Ref. [11] – shaded circle.

Figure 7. Ratio of experimental and quantum-mechanical line widths vs. atomic number. Li-like ions: circles, Be-like ions: squares. Ratios with the Belgrade data correspond to shadowed symbols, while ratios with the Bochum data correspond to open symbols.

Figure 8. Scaled (a) inelastic and (b) elastic CCC line widths. B III – solid line, C IV – short-dash line, N V – dotted line, O VI – dot-dashed line, F VII – long-dash line, Ne VIII – dot-double-dash line.

Table I. Electron-impact linewidths (in Å) for the $3s - 3p$ transition in B III – Ne VIII ions. The electron temperature T_e is in eV and the electron density is 10^{18} cm^{-3}.

T_e	B III			C IV			N V		
	el	inel	total	el	inel	total	el	inel	total
2	2.860	10.25	13.11	1.117	3.799	4.916	0.661	1.348	2.009
4	1.578	9.880	11.46	0.589	3.490	4.079	0.342	1.318	1.656
6	1.096	9.576	10.67	0.405	3.212	3.617	0.229	1.254	1.483
8	0.844	9.344	10.19	0.312	3.007	3.319	0.172	1.197	1.369
10	0.689	9.163	9.852	0.255	2.852	3.107	0.138	1.151	1.289
12	0.584	9.007	9.591	0.217	2.729	2.946	0.115	1.111	1.226
14	0.508	8.878	9.386	0.189	2.629	2.818	0.0981	1.076	1.174
16	0.450	8.747	9.197	0.168	2.544	2.712	0.0857	1.047	1.133
18	0.404	8.659	9.063	0.151	2.472	2.623	0.0761	1.021	1.097
20	0.367	8.531	8.898	0.137	2.410	2.547	0.0684	0.996	1.064

Table I (continued).

T_e	O VI			F VII			Ne VIII		
	el	inel	total	el	inel	total	el	inel	total
2	0.340	0.668	1.008	0.141	0.334	0.475	0.0732	0.177	0.250
4	0.178	0.664	0.842	0.0712	0.342	0.413	0.0413	0.182	0.223
6	0.118	0.624	0.743	0.0490	0.327	0.376	0.0289	0.176	0.205
8	0.0881	0.588	0.676	0.0382	0.310	0.348	0.0226	0.169	0.192
10	0.0701	0.558	0.629	0.0318	0.295	0.327	0.0187	0.162	0.180
12	0.0581	0.533	0.591	0.0274	0.282	0.310	0.0161	0.156	0.172
14	0.0496	0.513	0.562	0.0242	0.271	0.296	0.0141	0.150	0.165
16	0.0433	0.496	0.539	0.0217	0.262	0.284	0.0126	0.146	0.159
18	0.0384	0.481	0.519	0.0197	0.254	0.273	0.0114	0.143	0.154
20	0.0345	0.468	0.503	0.0180	0.247	0.265	0.0104	0.139	0.150
30							0.0073	0.128	0.135
40							0.0055	0.120	0.125
50							0.0044	0.114	0.119